EFFECTS OF PILE DRIVING ON FISH AND WILDLIFE

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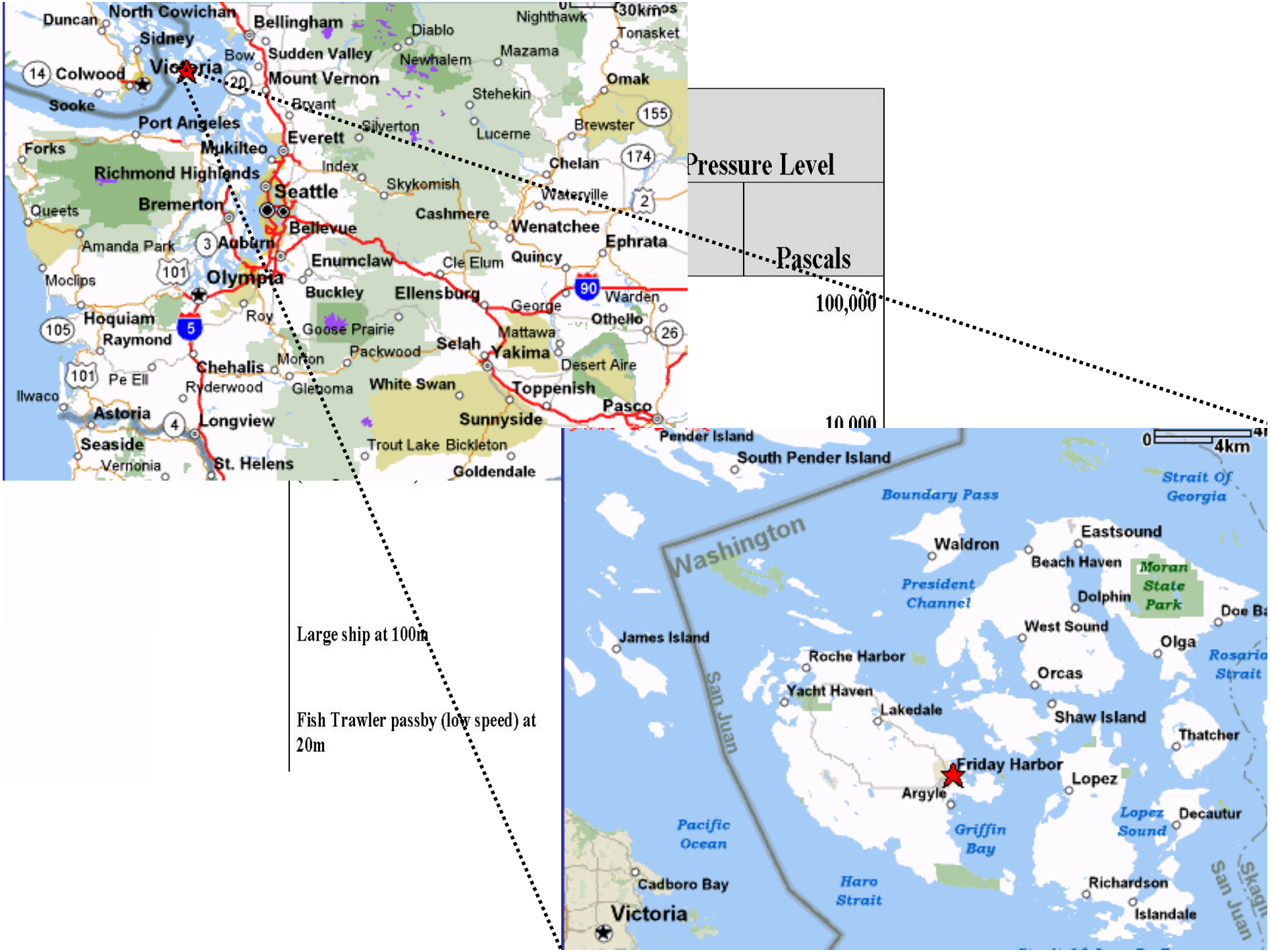
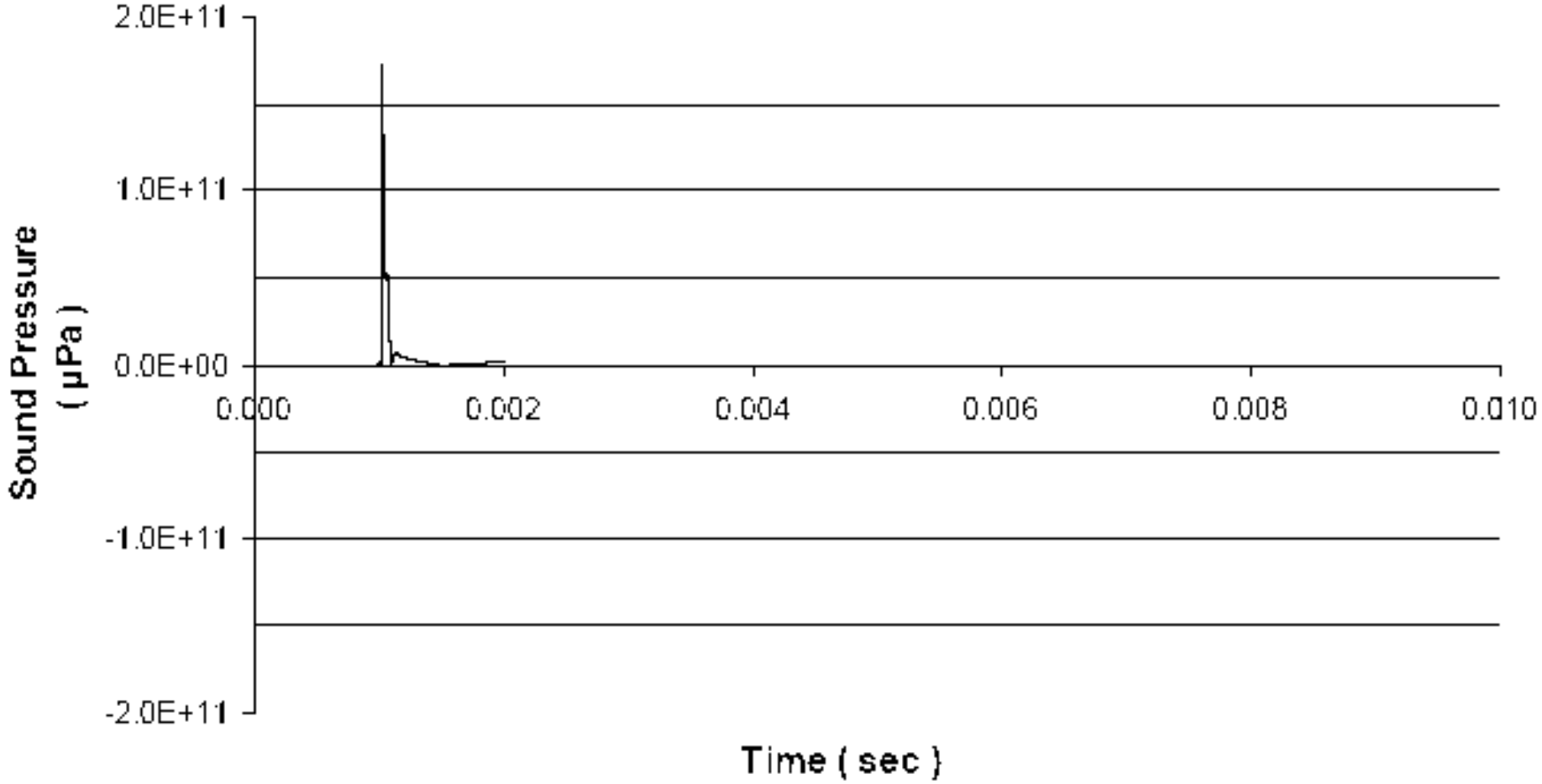

Duncan
North Cowichan
Sidney
Victoria
Colwood
Sooke
Bellingham
Bow
Sudden Valley
Mount Vernon
Diablo
Newhalem
Nighthawk
Mazama
Tonasket
30km
Omak
Stehekin
Bryant
Silverton
Lucerne
Brewster
Port Angeles
Everett
Forks
Mukilteo
Richmond Highlands
Index
Skykomish
Chelan
Waterville
Seattle
Bremerton
Queets
Cashmere
Wenatchee
Bellevue
Ephrata
Amanda Park
Auburn
Enumclaw
Cle Elum
Quincy
Moclips
Olympia
Buckley
Ellensburg
George
Warden
Hoquiam
Roy
Goose Prairie
Othello
Raymond
Mattawa
Selah
Yakima
Packwood
Chehalis
Morton
Desert Aire
Pe Ell
Ryderwood
Glenoma
White Swan
Toppenish
Ilwaco
Pasco
Astoria
Longview
Sunnyside
Seaside
Trout Lake
Bickleton
Vernonia
St. Helens
Goldendale
Pressure Level
Pascals
100,000
10,000
Large ship at 100m
Fish Trawler passby (low speed) at 20m
Pender Island
South Pender Island
0
4km
Strait Of Georgia
Boundary Pass
Washington
Eastsound
Waldron
Beach Haven
Moran State Park
President Channel
Dolphin
West Sound
James Island
Olga
Roche Harbor
Orcas
Rosario Strait
Yacht Haven
Lakedale
Shaw Island
San Juan
Thatcher
Friday Harbor
Lopez
Argyle
Lopez Sound
Decautur
Pacific Ocean
Griffin Bay
Cadboro Bay
Haro Strait
Richardson
Victoria
Islandale
Skagit
San Juan

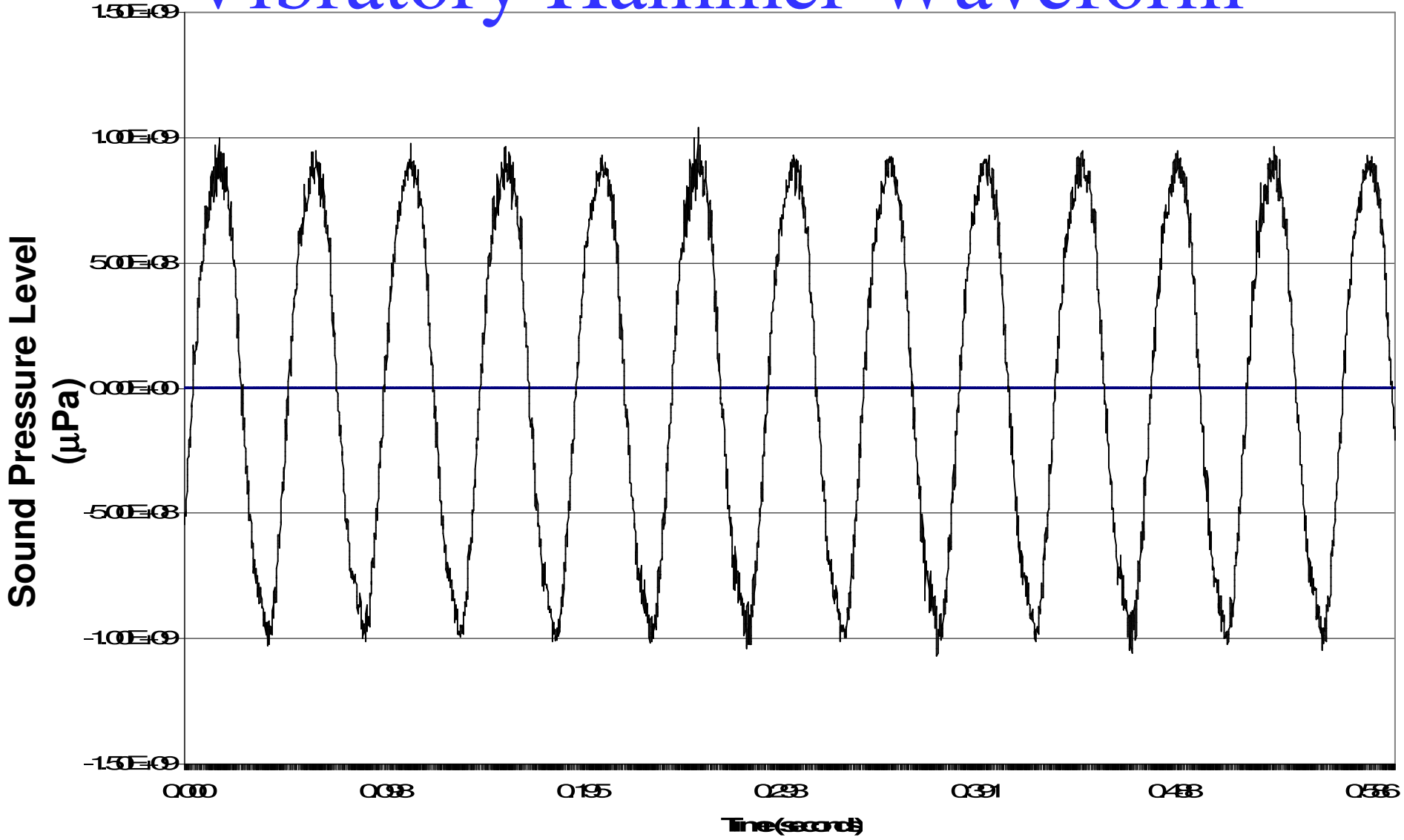
Hydroacoustics Background

- Underwater pile driving impacts to fish began to appear around 1995 in California and B.C.
- Decibels: 20 log (p/p_{ref})
  - Airborne noise: ref = 20 µPa.
  - Underwater noise: ref = 1 µPa.

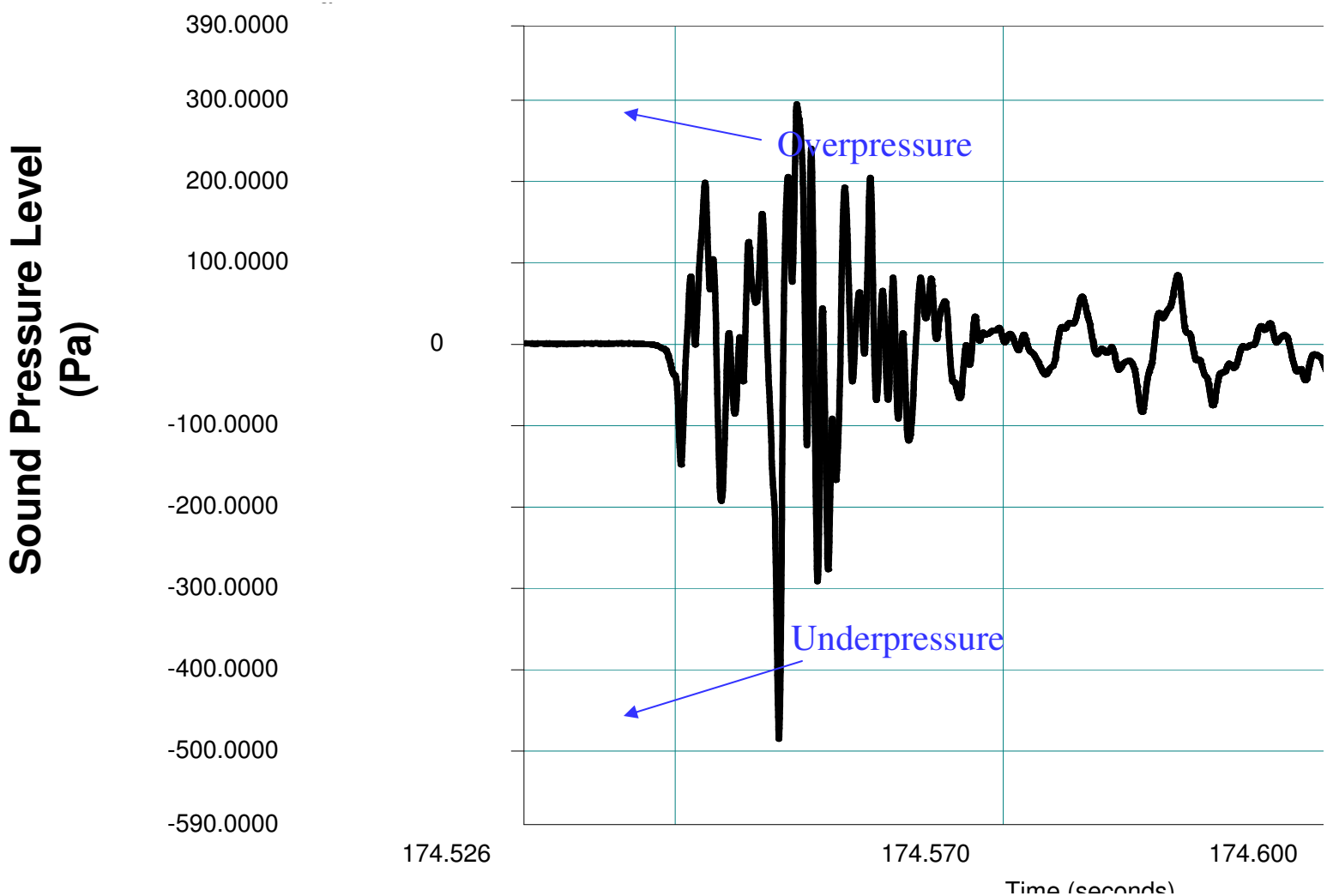
Underwater Blast Waveform



Vibratory Hammer Waveform



Impact Driving Waveform



Ruptured Swim Bladder (Surf Perch)

Internal Bleeding

Photos by Bud Abbott

Sub-Lethal Effects

- Pile driving may damage inner ear (hair cells)
- Ear damage may be short term or permanent
- Hearing impairments may possibly increase predation
- Hearing impairments may possibly alter reproduction or feeding
- Not well studied

Normal Fish Hair Cells

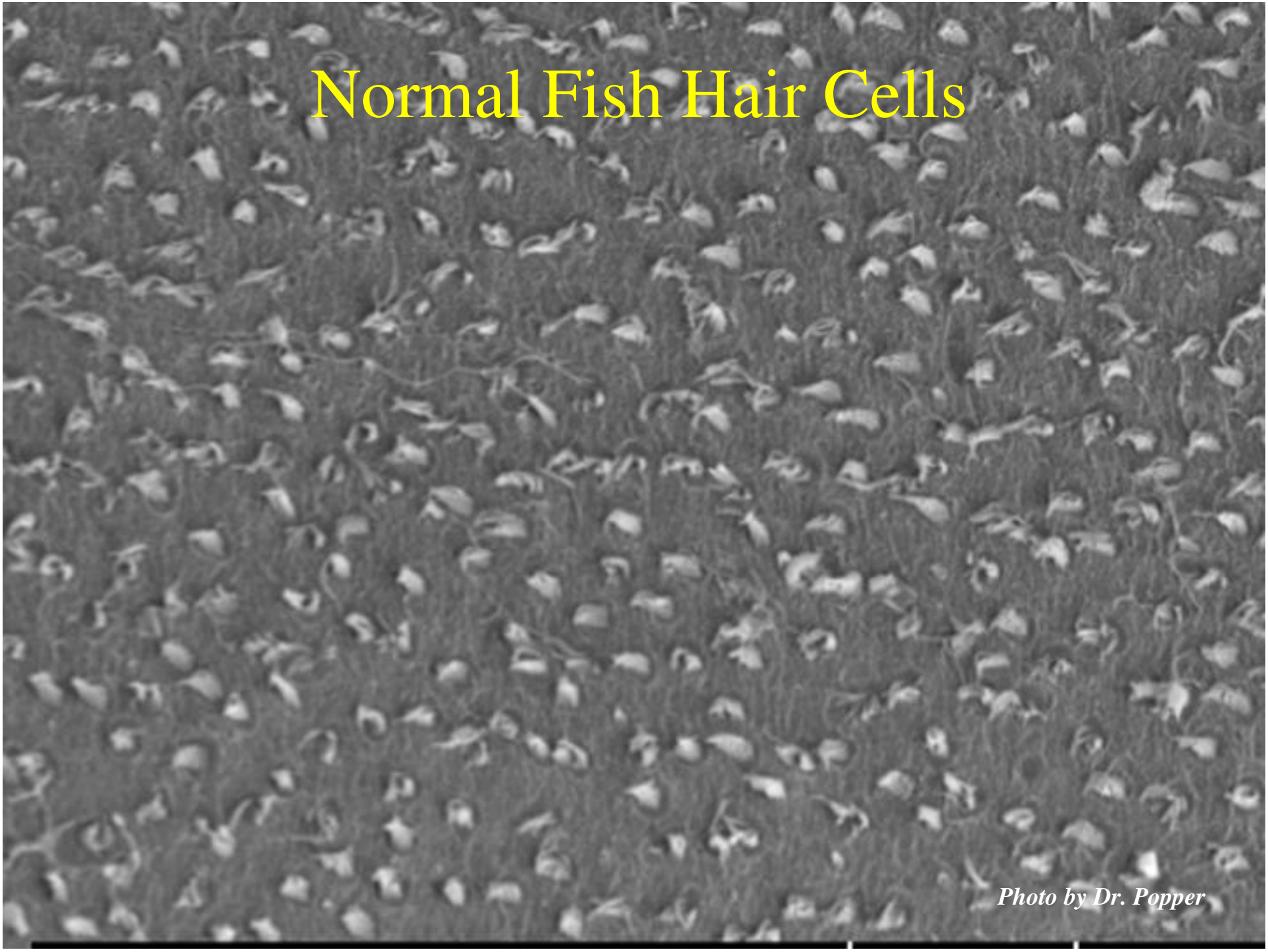


Photo by Dr. Popper

Damaged Fish Hair Cells
(180-190 dB)

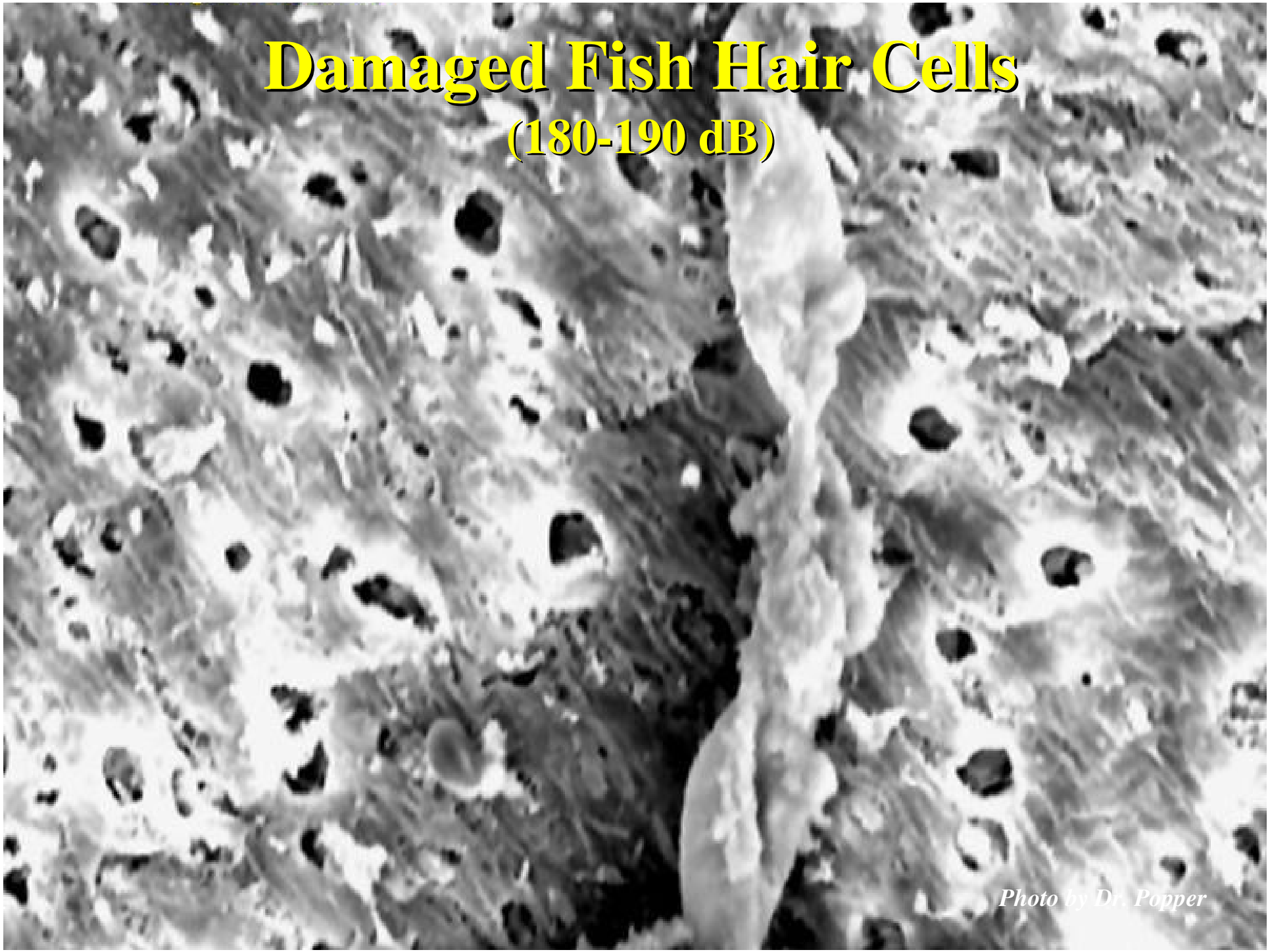
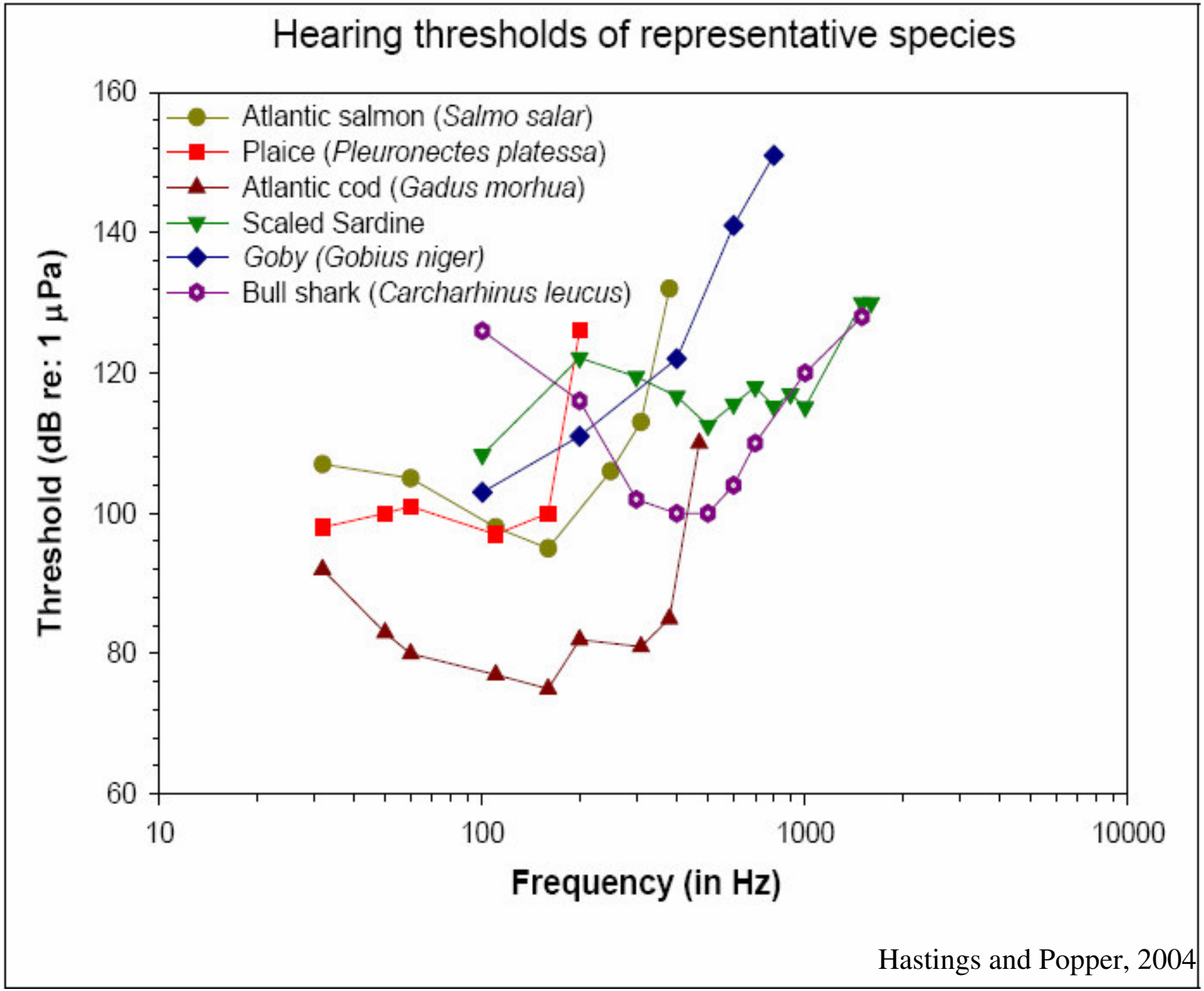
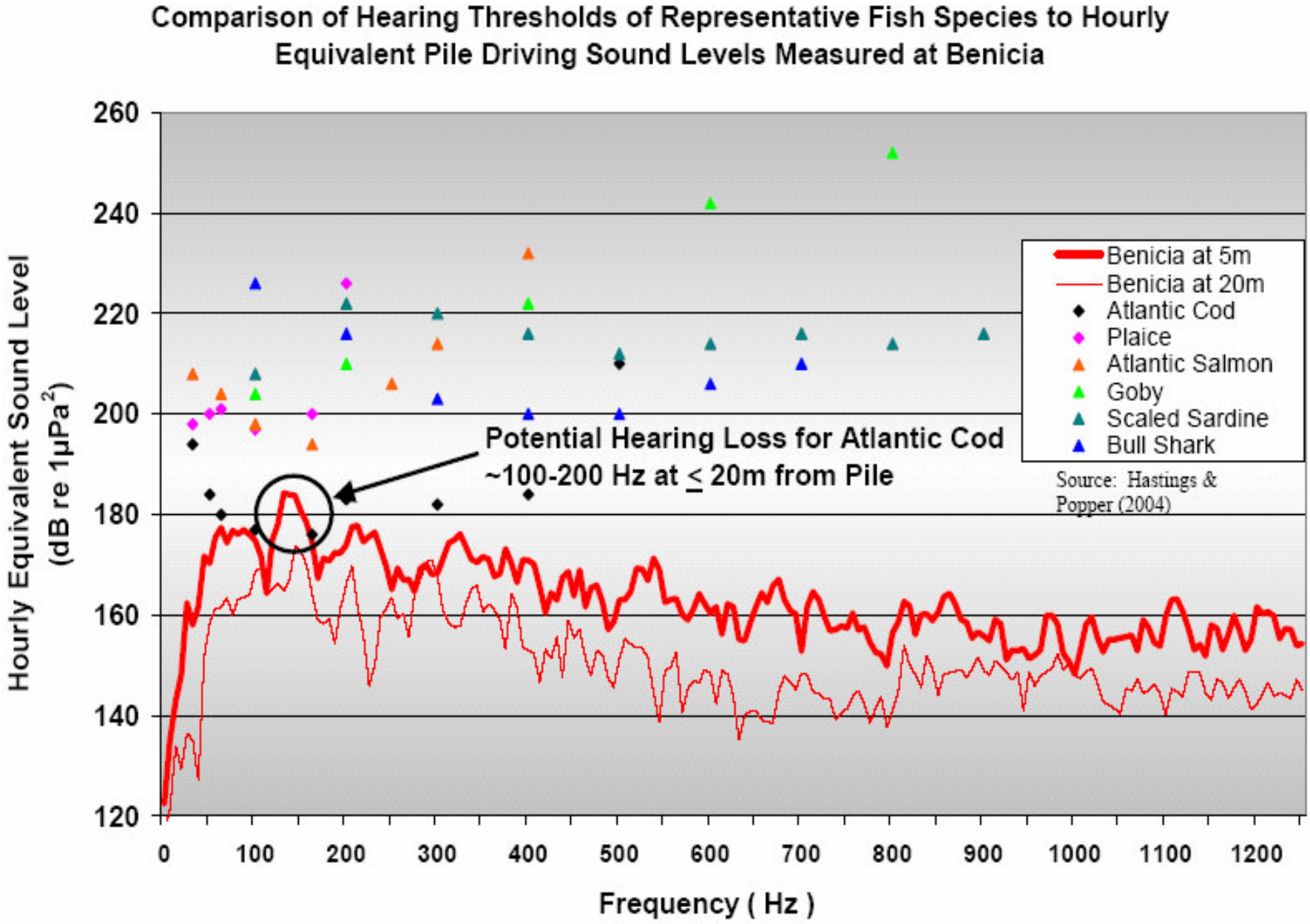


Photo by Dr. Popper

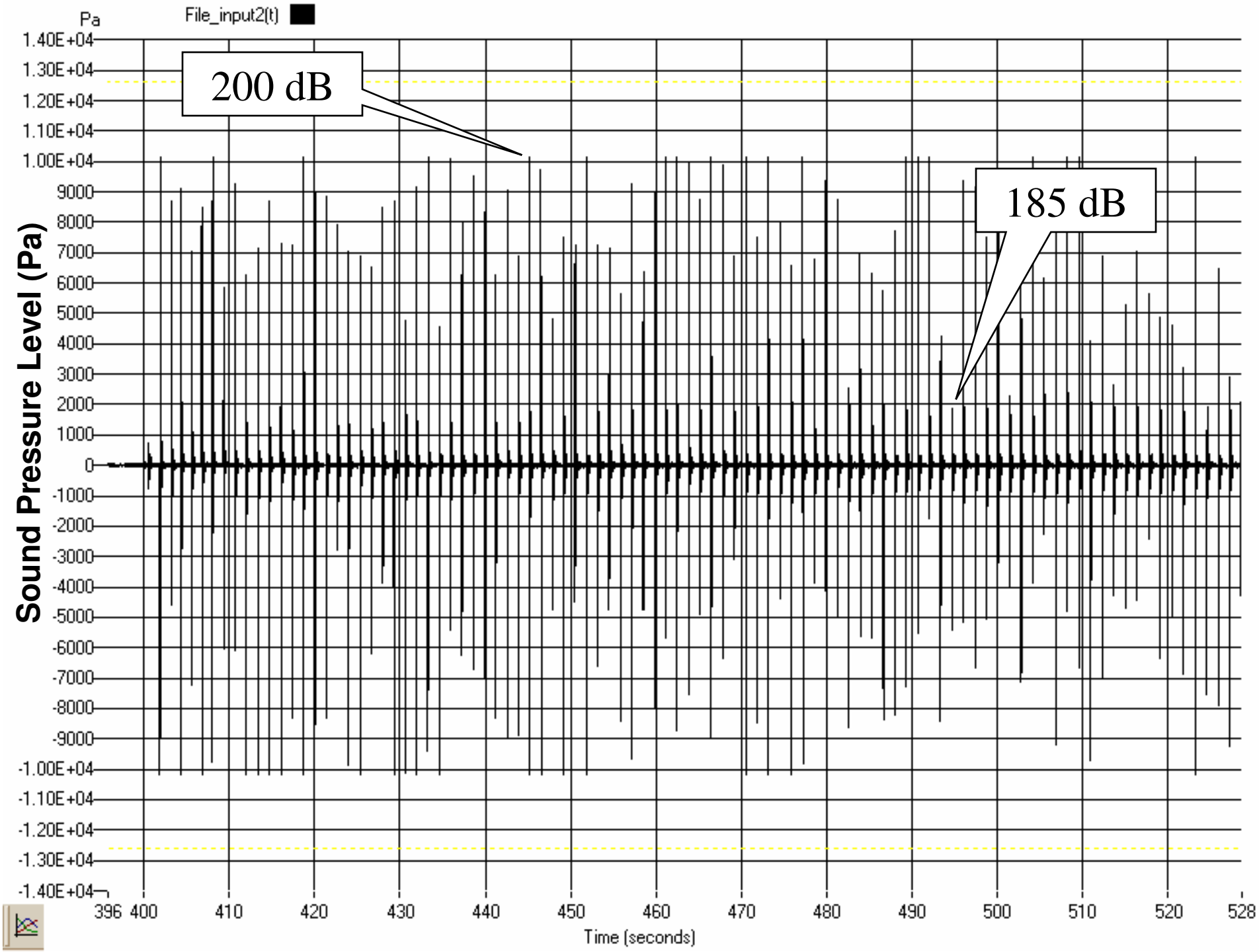


Hastings and Popper, 2004


Comparison of Hearing Thresholds of Representative Fish Species to Hourly Equivalent Pile Driving Sound Levels Measured at Benicia
Hourly Equivalent Sound Level (dB re 1µPa²)
260
240
220
200
180
160
140
120
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Frequency (Hz)
Benicia at 5m
Benicia at 20m
Atlantic Cod
Plaice
Atlantic Salmon
Goby
Scaled Sardine
Bull Shark
Potential Hearing Loss for Atlantic Cod
~100-200 Hz at ≤ 20m from Pile
Source: Hastings & Popper (2004)

What Do We Measure?

- Sound Pressure Peak dB?


Pa
File_input2(t)
200 dB
185 dB
Sound Pressure Level (Pa)
1.40E+04
1.30E+04
1.20E+04
1.10E+04
1.00E+04
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-1.00E+04
-1.10E+04
-1.20E+04
-1.30E+04
-1.40E+04
396 400 410 420 430 440 450 460 470 480 490 500 510 520 528
Time (seconds)

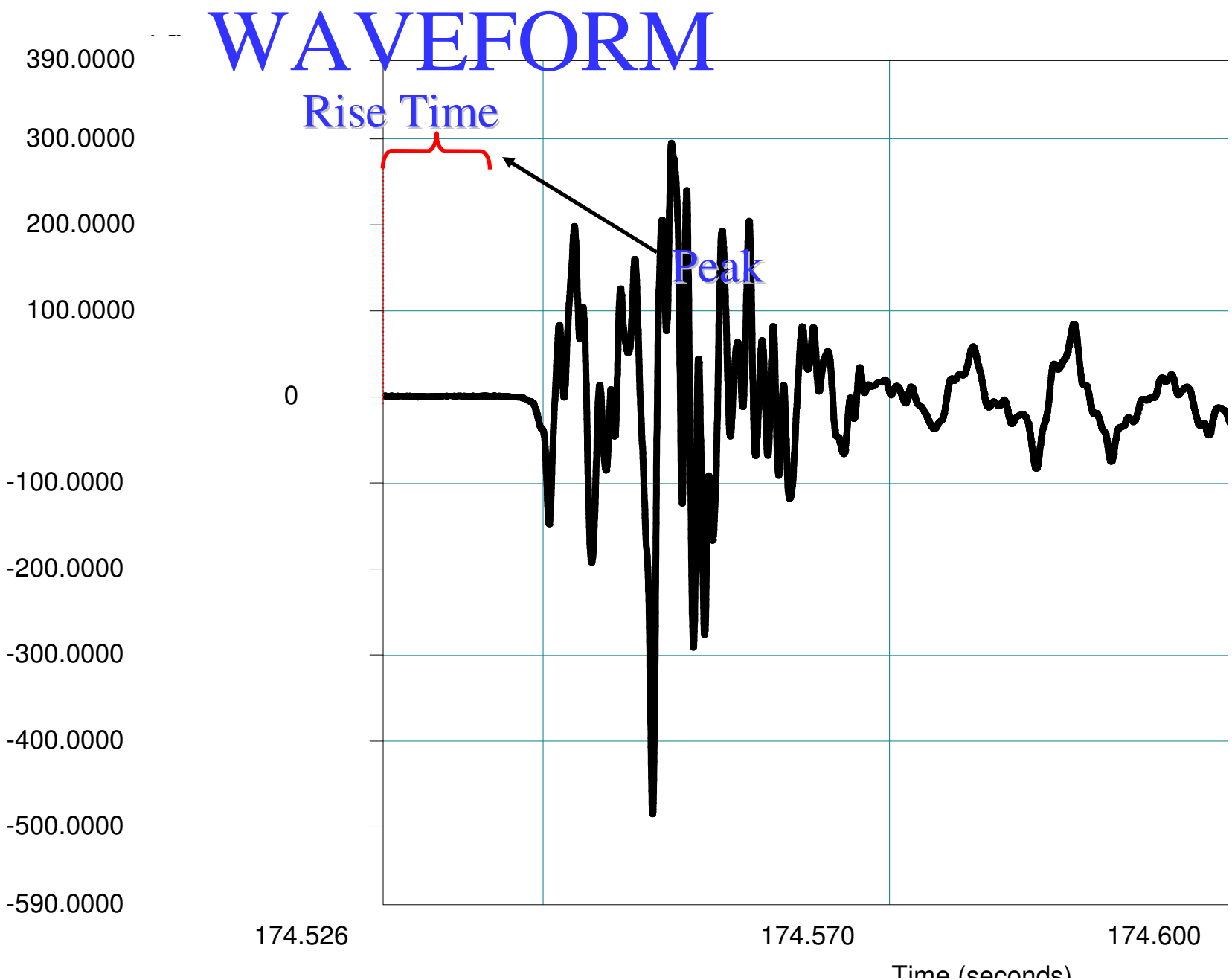
Piles (180 dB_{peak} – NOAA threshold)

PILE TYPE	dB_{peak} re: 1 µ Pa
H-piles (steel)	150 - 160
Timber pile (diameter variable)	160 - 177
24-inch dia. concrete pile	183 - 193
12-inch dia. steel pile	177 – 190
14-inch dia. steel pile	195 – 200
24-inch dia. steel pile	202 - 210

Vibratory driving 10-20 dB re: 1 µPa lower

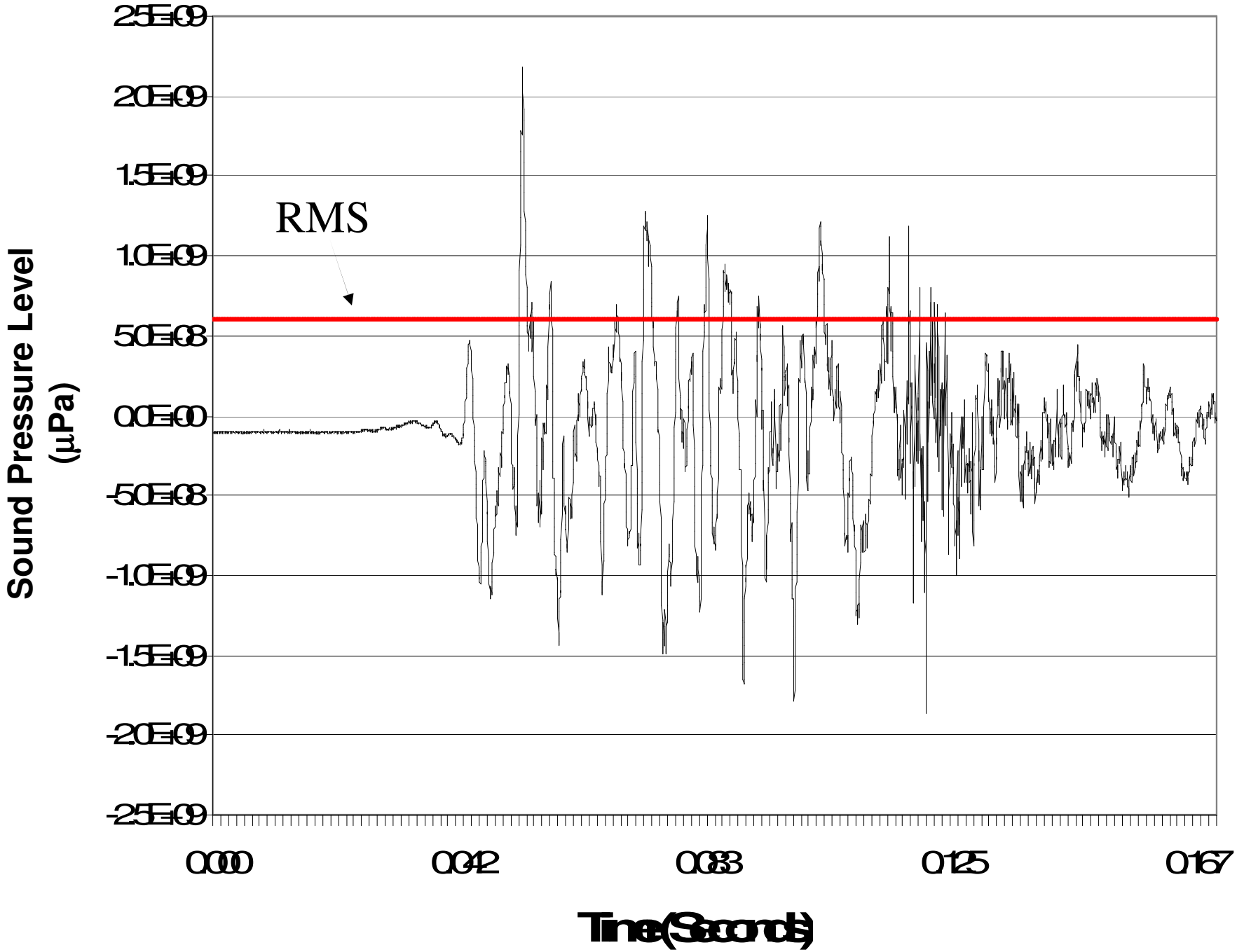
What Do We Measure?

- Sound Pressure Peak dB?
- Rise Time?


WAVEFORM
Rise Time
Peak
390.0000
300.0000
200.0000
100.0000
0
-100.0000
-200.0000
-300.0000
-400.0000
-500.0000
-590.0000
174.526
174.570
174.600
Time (seconds)

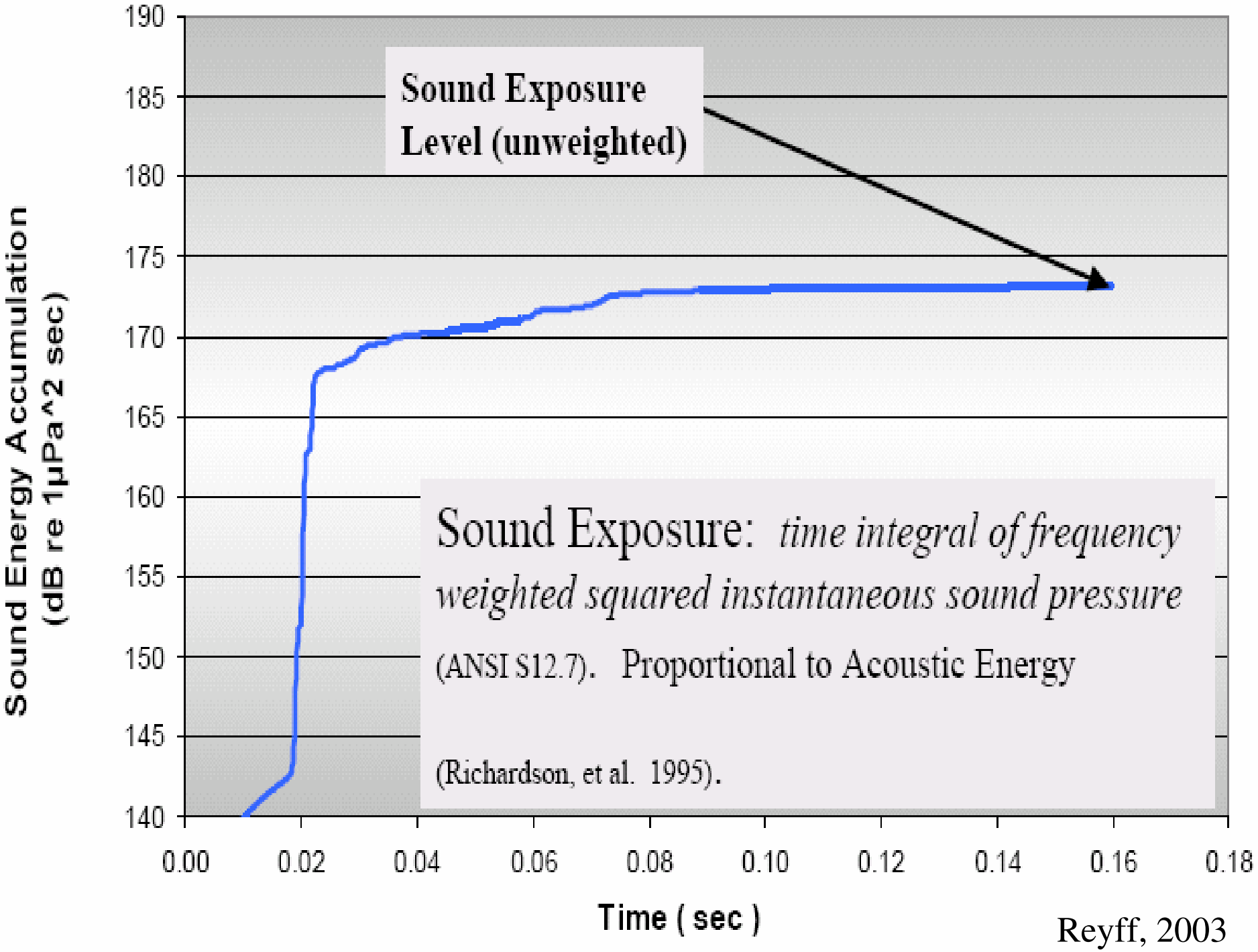
What Do We Measure?

- Sound Pressure Peak dB?
- Rise Time?
- Root Mean Square (RMS)?


2.5E+09
2.0E+09
1.5E+09
1.0E+09
5.0E+08
0.0E+00
-5.0E+08
-1.0E+09
-1.5E+09
-2.0E+09
-2.5E+09
RMS
Sound Pressure Level (µPa)
0.000
0.042
0.083
0.125
0.167
Time (Seconds)

What Do We Measure?

- Sound Pressure Peak dB?
- Rise Time?
- Root Mean Square (RMS)?
- Sound Exposure Level (SEL)?


Sound Exposure Level (unweighted)
Sound Exposure: time integral of frequency weighted squared instantaneous sound pressure
(ANSI S12.7). Proportional to Acoustic Energy
(Richardson, et al. 1995).
Sound Energy Accumulation (dB re 1µPa^2 sec)
Time (sec)
190
185
180
175
170
165
160
155
150
145
140
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18

Reyff, 2003

Representative Pile Strike at 10 meters - Timber (12 inches) w/Drop Hammer

Figure a. Waveform

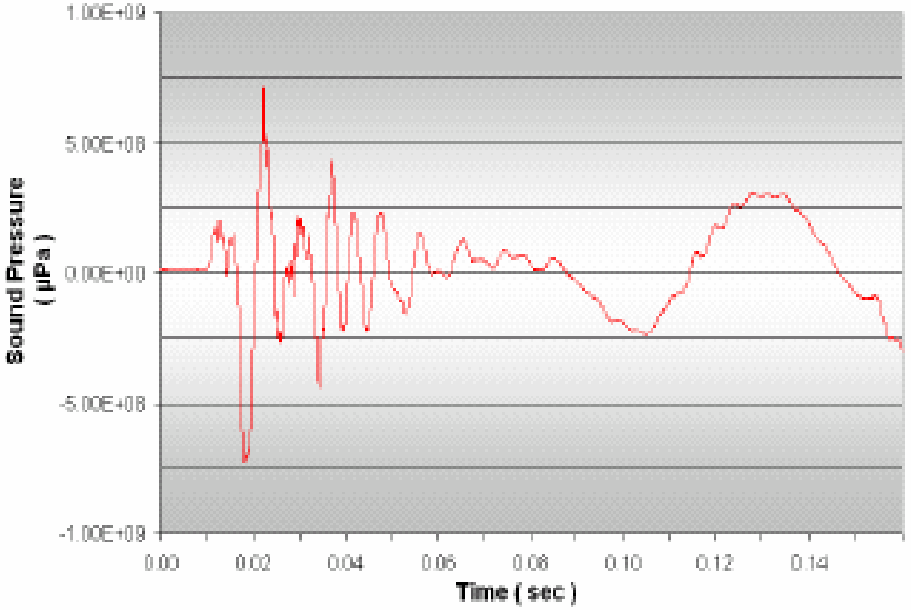


Figure b. Narrow Band Frequency Spectra

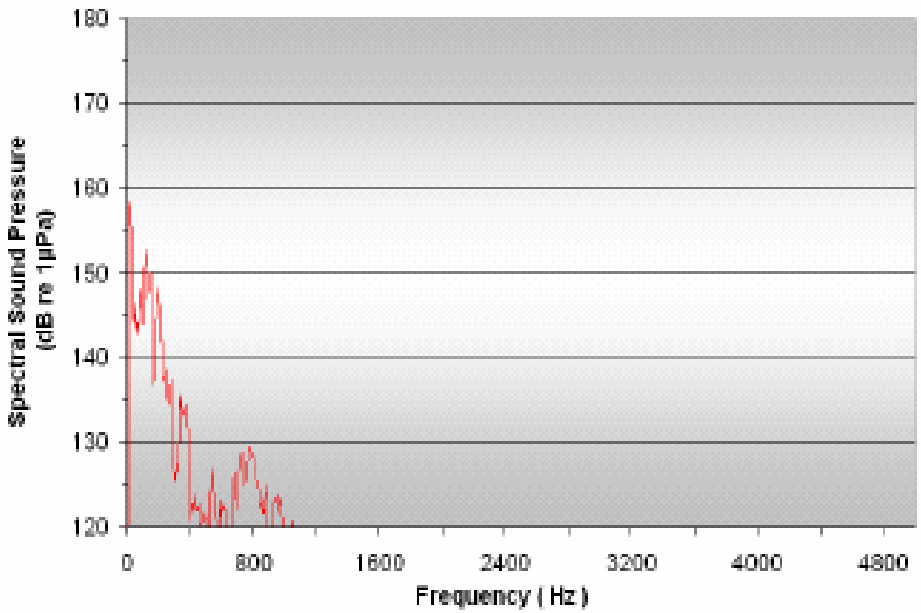


Figure c. Accumulation of Sound Energy

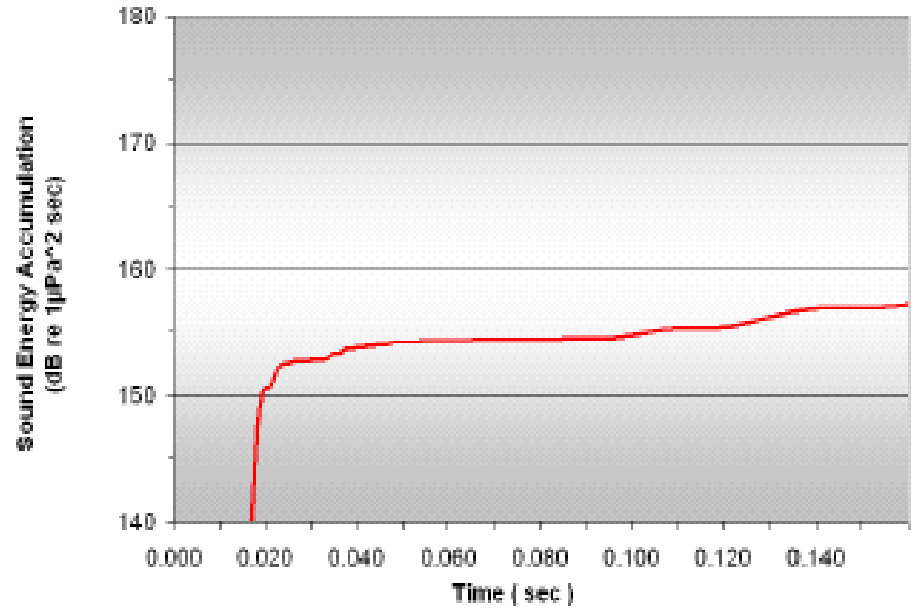


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Timber - 12 inch Diameter	Peak	RMS90%*	SEL
Drop	177	165	157

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**
Sound Level Meter Measurement	175	165

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Representative Pile Strike at 10 meters - Concrete (24 inches) w/Impact Hammer

Figure a. Waveform

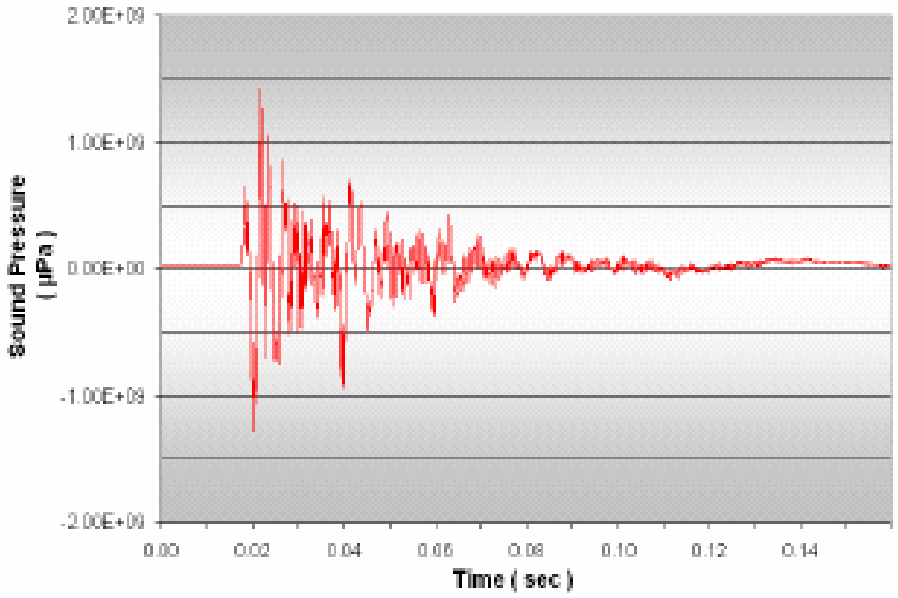


Figure b. Narrow Band Frequency Spectra

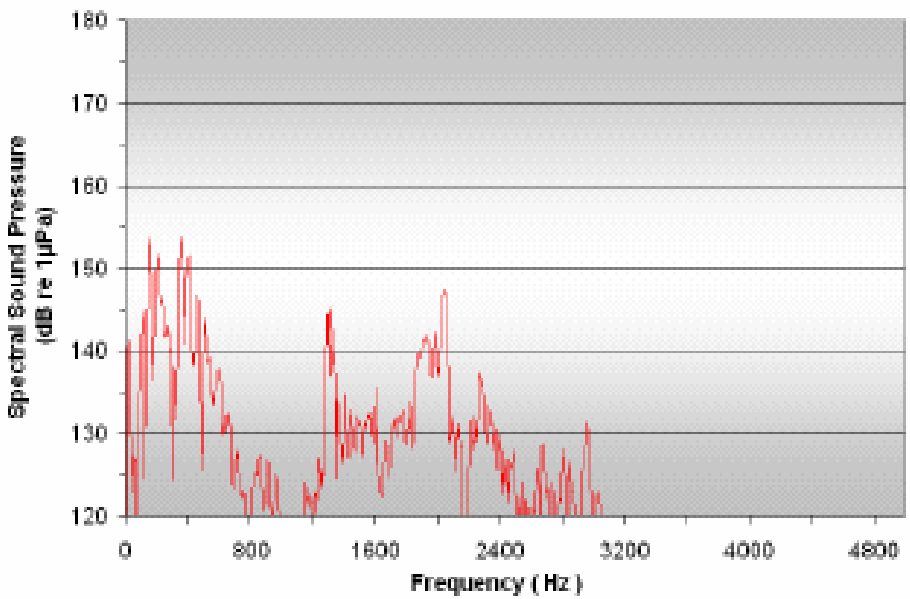


Figure c. Accumulation of Sound Energy

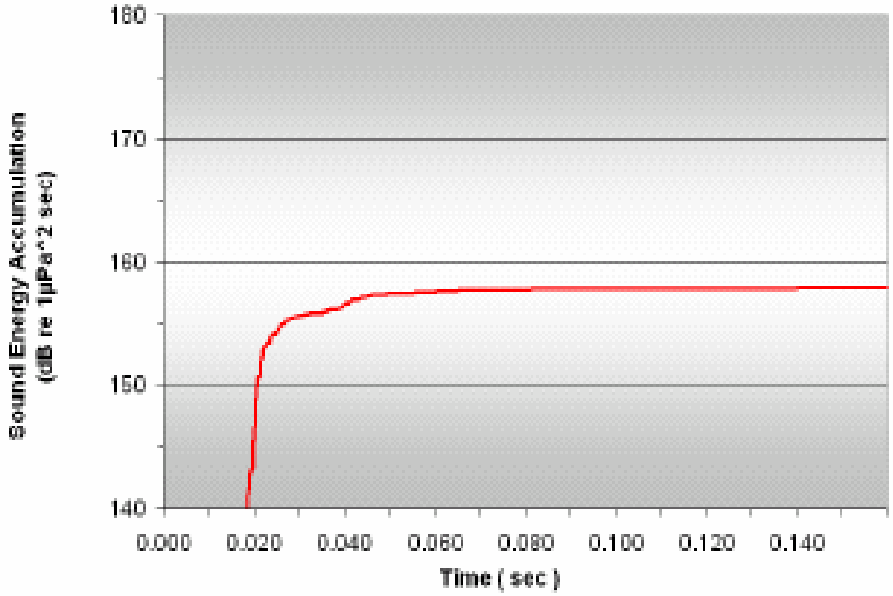


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

Concrete - 24 inch Diameter	Peak	RMS90%*	SEL
Impact	183	171	158

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS35ms**
Sound Level Meter Measurement	208	193

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Representative Pile Strike at 10 meters - CISS (30 inches) w/Impact Hammer

Figure a. Waveform

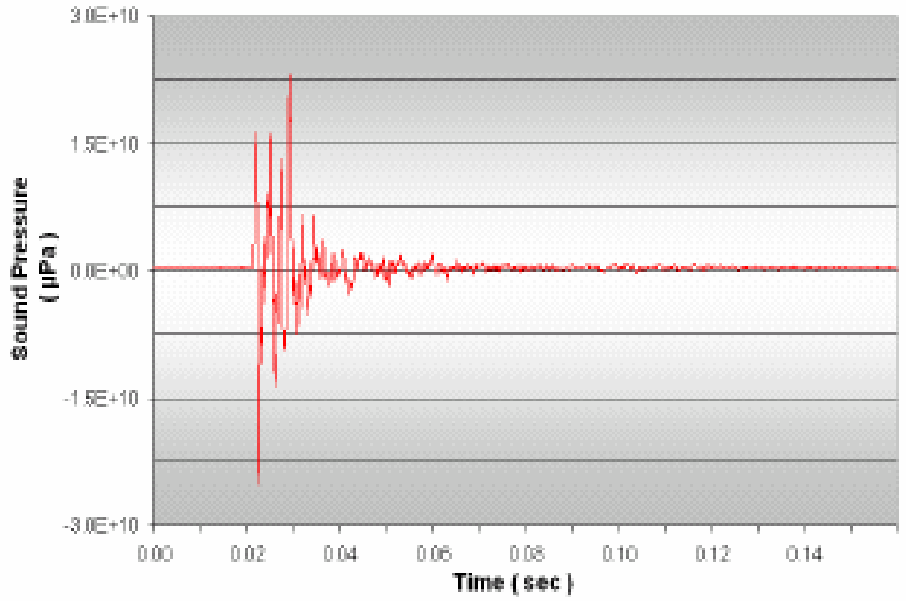


Figure b. Narrow Band Frequency Spectra

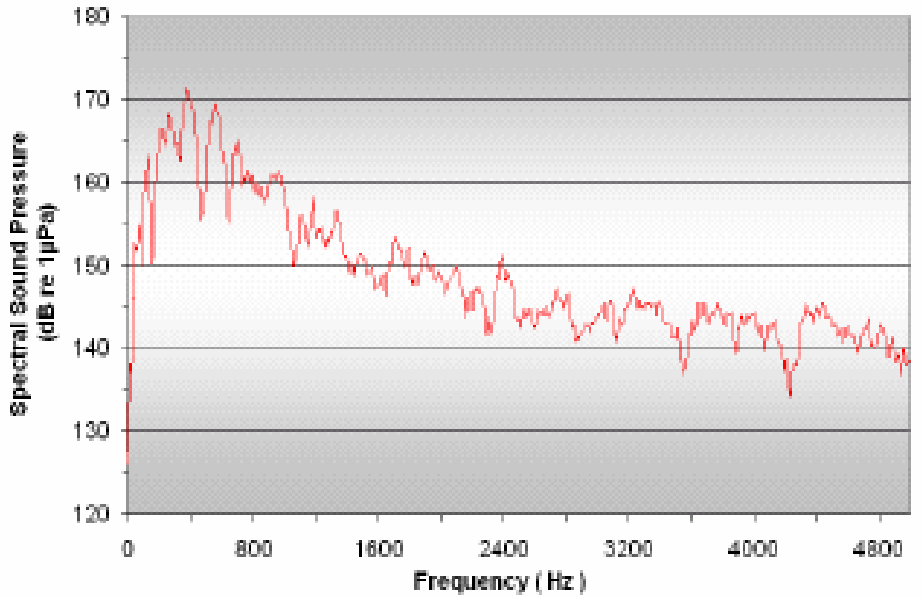


Figure c. Accumulation of Sound Energy

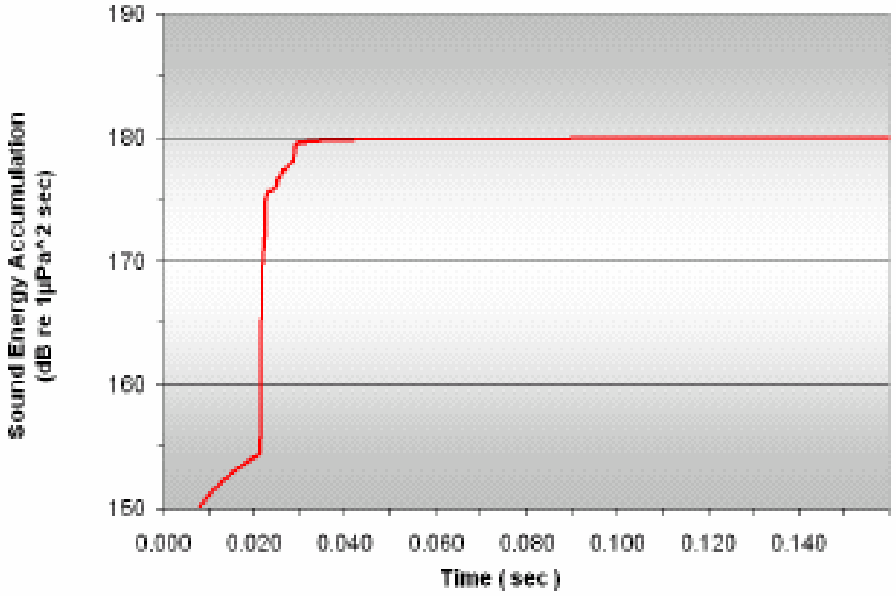


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

CISS - 30 inch Diameter	Peak	$RMS_{90\%}$*	SEL
Impact	208	198	180

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS_{35ms}**
Sound Level Meter Measurement	208	199

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Reyff, 2003

Comparison with Pile Driving Signals at 10 Meters

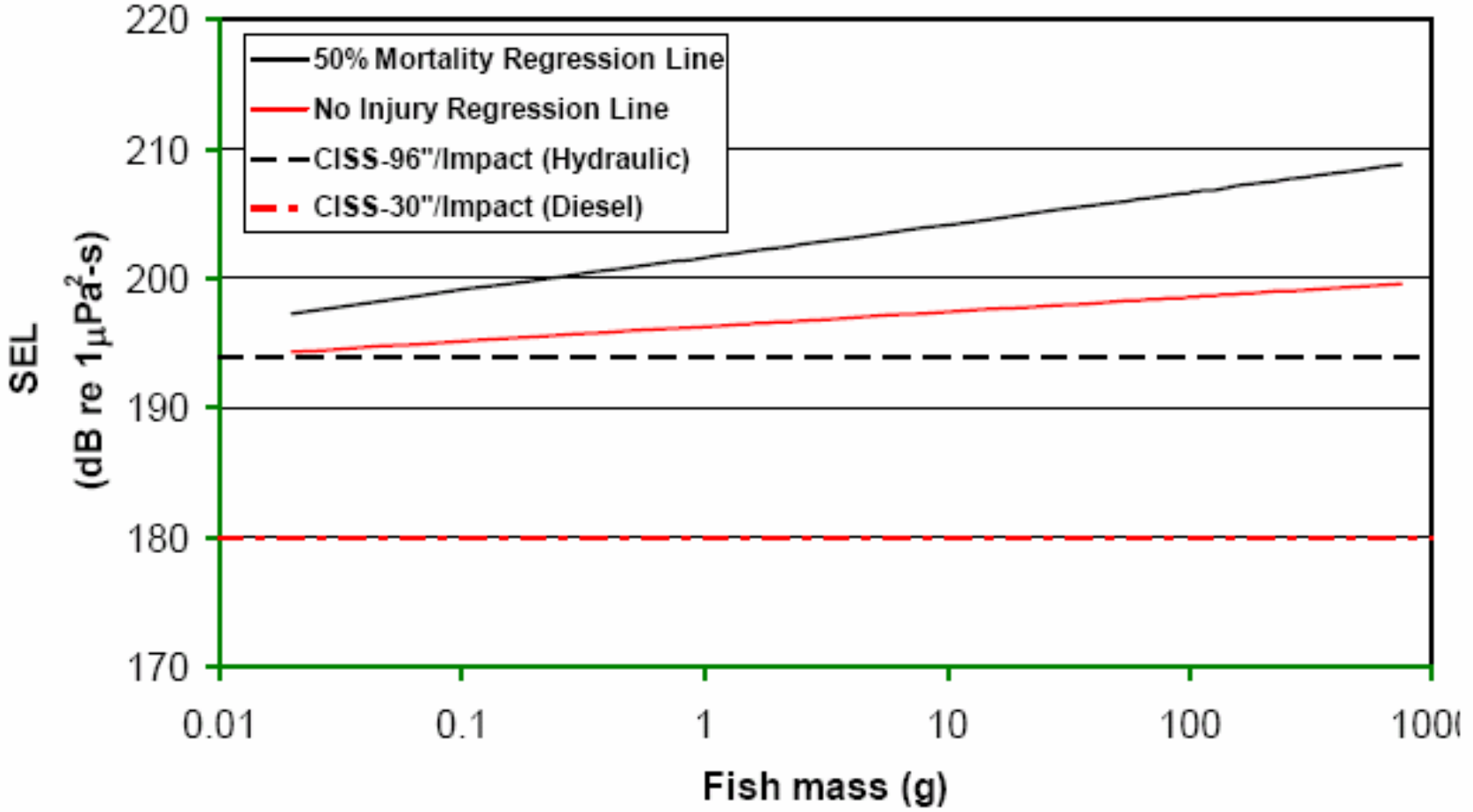


Figure B-1: Comparison of received SEL at 10 meters with the recommended guidance for physical injury and 50% mortality

Hastings and Popper, 2004

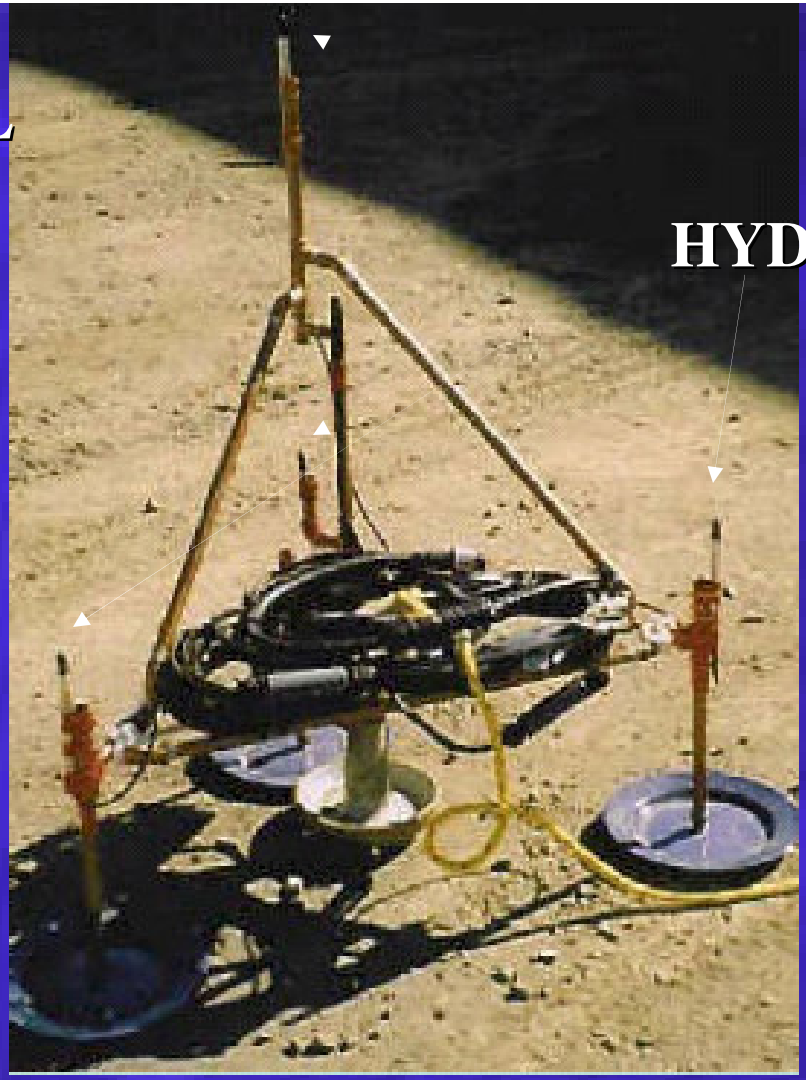
What Do We Measure?

- Sound Pressure Peak dB?
- Rise Time?
- Root Mean Square (RMS)?
- Sound Exposure Level (SEL)
- Acoustical Particle Velocity

Sound Pressure & Particle Velocity

- Humans hear Sound Pressure.
- Most fish hear Acoustic Particle Velocity also known as Sound Intensity:
- $I = pV$
- Intensity also “points” in the direction of sound propagation

ACOUSTICAL PARTICLE VELOCITY



HYDROPHONES

MITIGATION

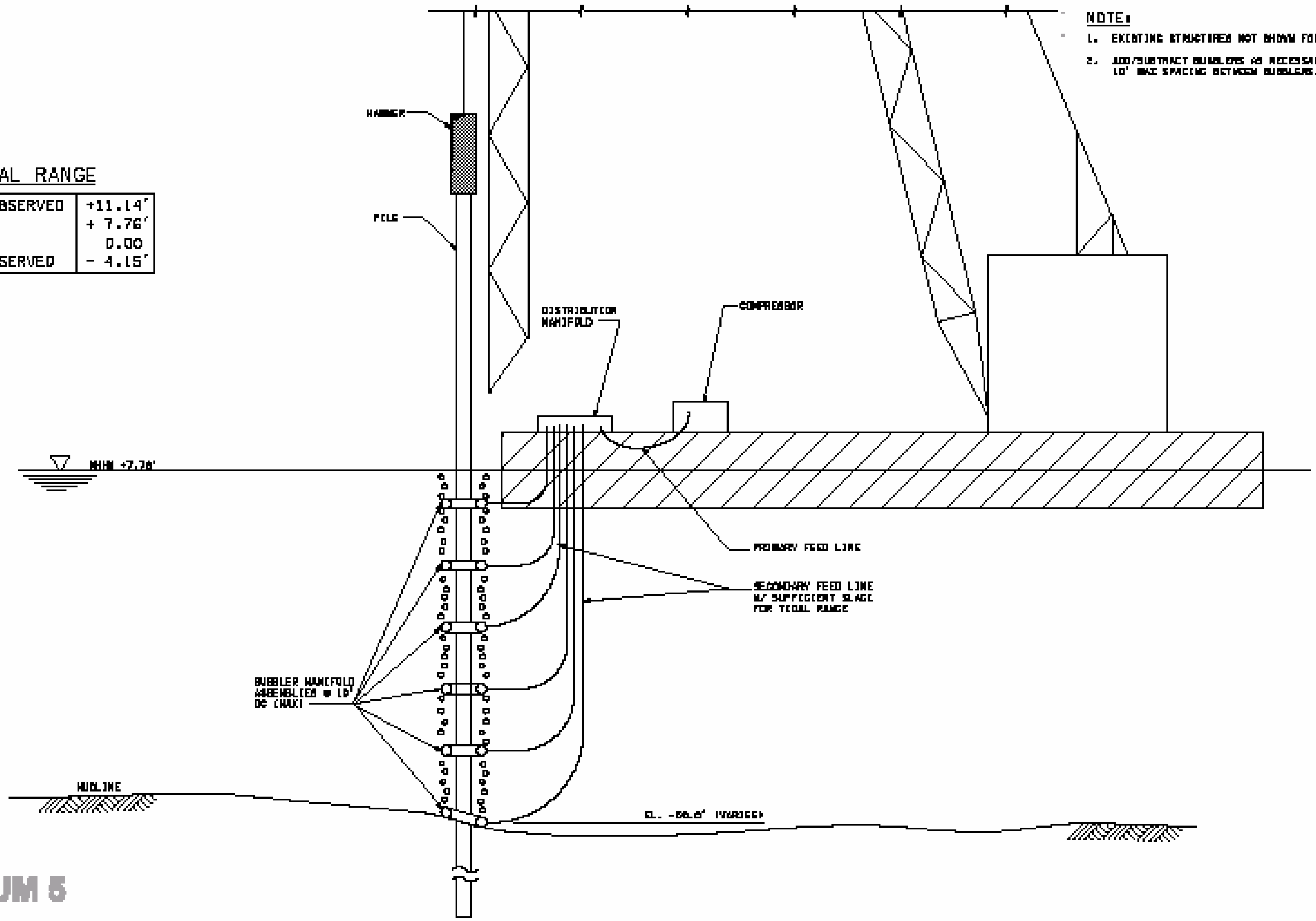
- Bubble Curtain – 5 dB to 15 dB reduction
- Friday Harbor: $4,000 per pile

TIDAL RANGE

HIGHEST OBSERVED	+11.14'
MHHW	+ 7.76'
MLLW	0.00
LOWEST OBSERVED	- 4.15'

NOTE:

1. EXISTING STRUCTURES NOT SHOWN FOR CLARITY.
2. ADD/SUBTRACT BUBBLERS AS NECESSARY TO ACHIEVE 10' MAX SPACING BETWEEN BUBBLERS.



ADDENDUM 5

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SUBMITTAL DATE:	[illegible]			
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ENTERED BY:	05/10/2004			
CHECKED BY:	05/10/2004			
WSF PROJ ENGR:	05/10/2004			
WSF PROJ MGMT & TERM PLAN: J. COLBY				
WSF CEO: M. THORNE		REVISION	DATE	BY

FED.AID PROJ.NO. [illegible]
10 WASH
XL [illegible]
OD [illegible]

Washington State Department of Transportation
WASHINGTON STATE FERRIES

FRIDAY HARBOR PRESERVATION PROJECT

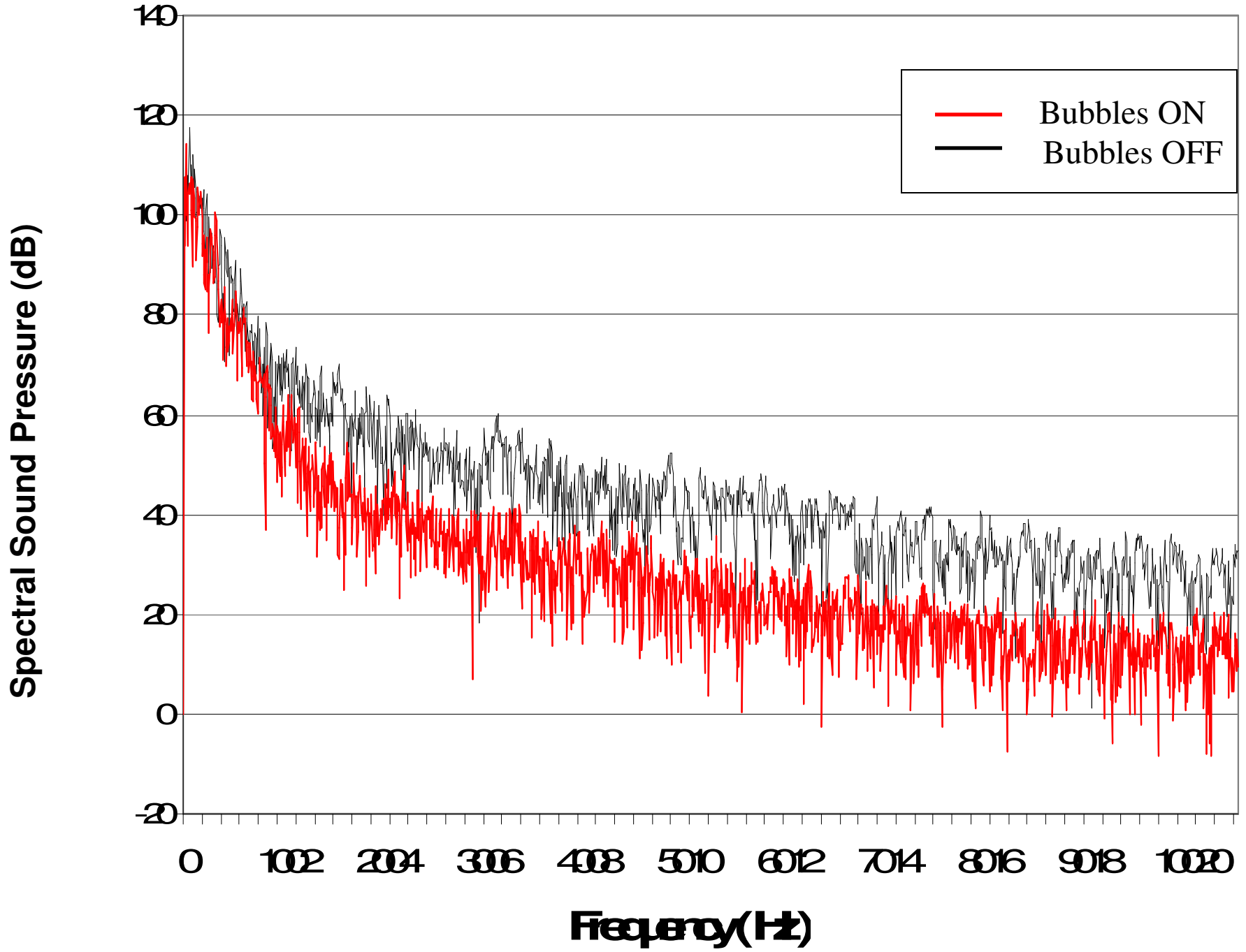
BUBBLE CURTAIN ARRANGEMENT

C11.00A

SHEET 51A OF 415 SHEETS


Bubble Curtain


Bubble Curtain

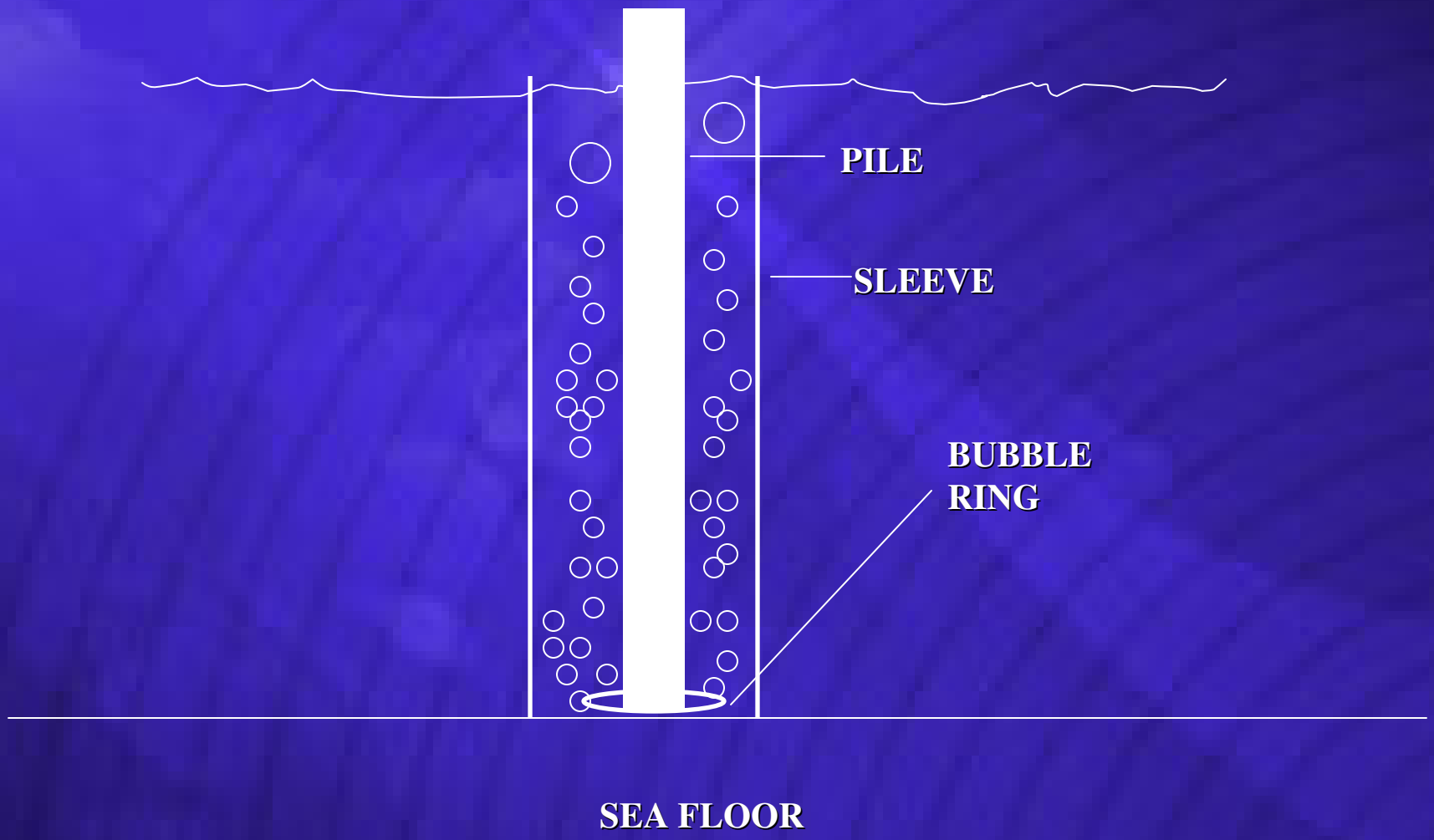

Spectral Sound Pressure (dB)
140
120
100
80
60
40
20
0
-20
0
102
204
306
408
510
612
714
816
918
1020
Frequency (Hz)
Bubbles ON
Bubbles OFF

MITIGATION

- Bubble Curtain
- Sleeves – 10 dB to 20 dB reduction

  Cost slightly higher than bubble curtain

CONFINED BUBBLE CURTAIN (TYPE II)

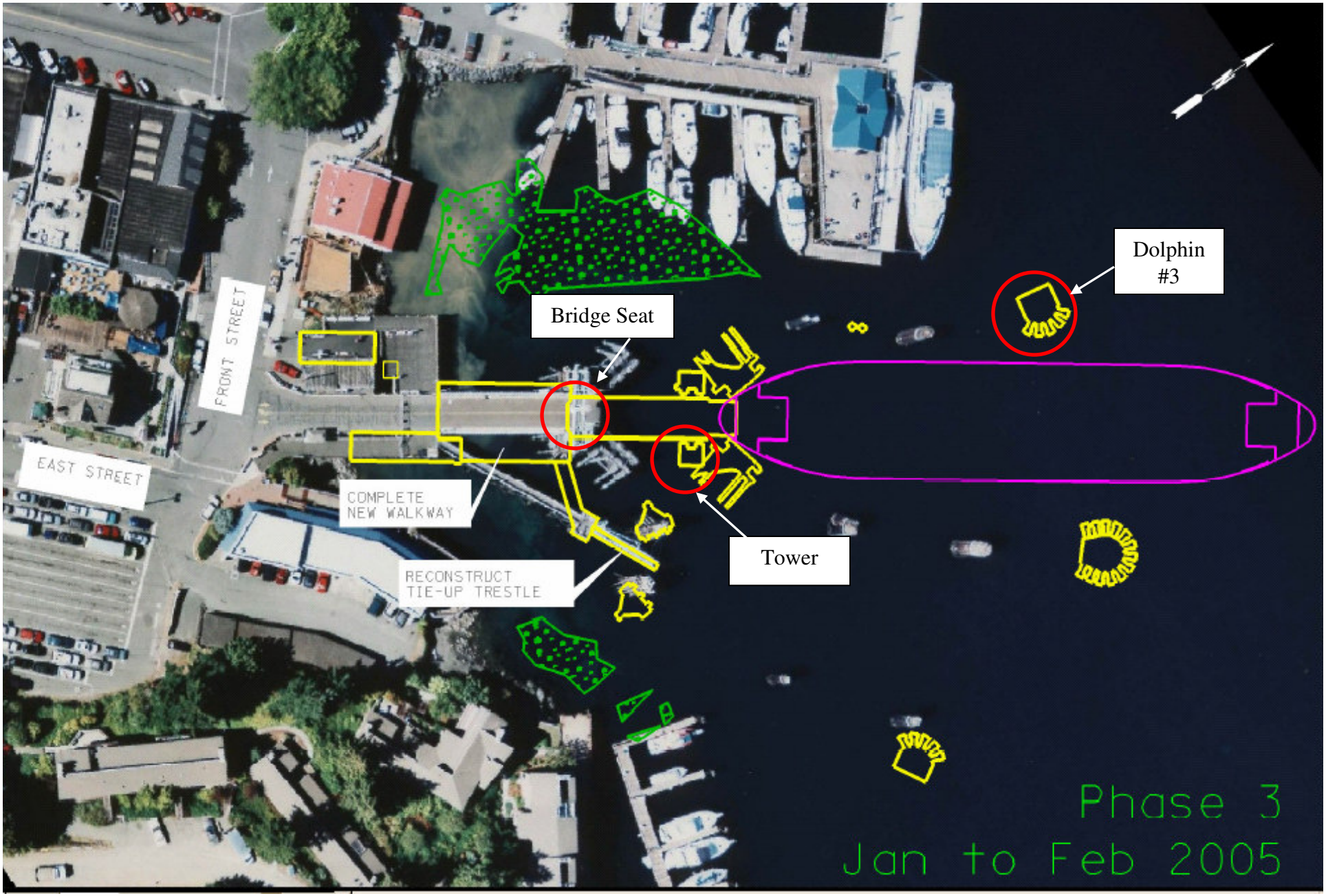


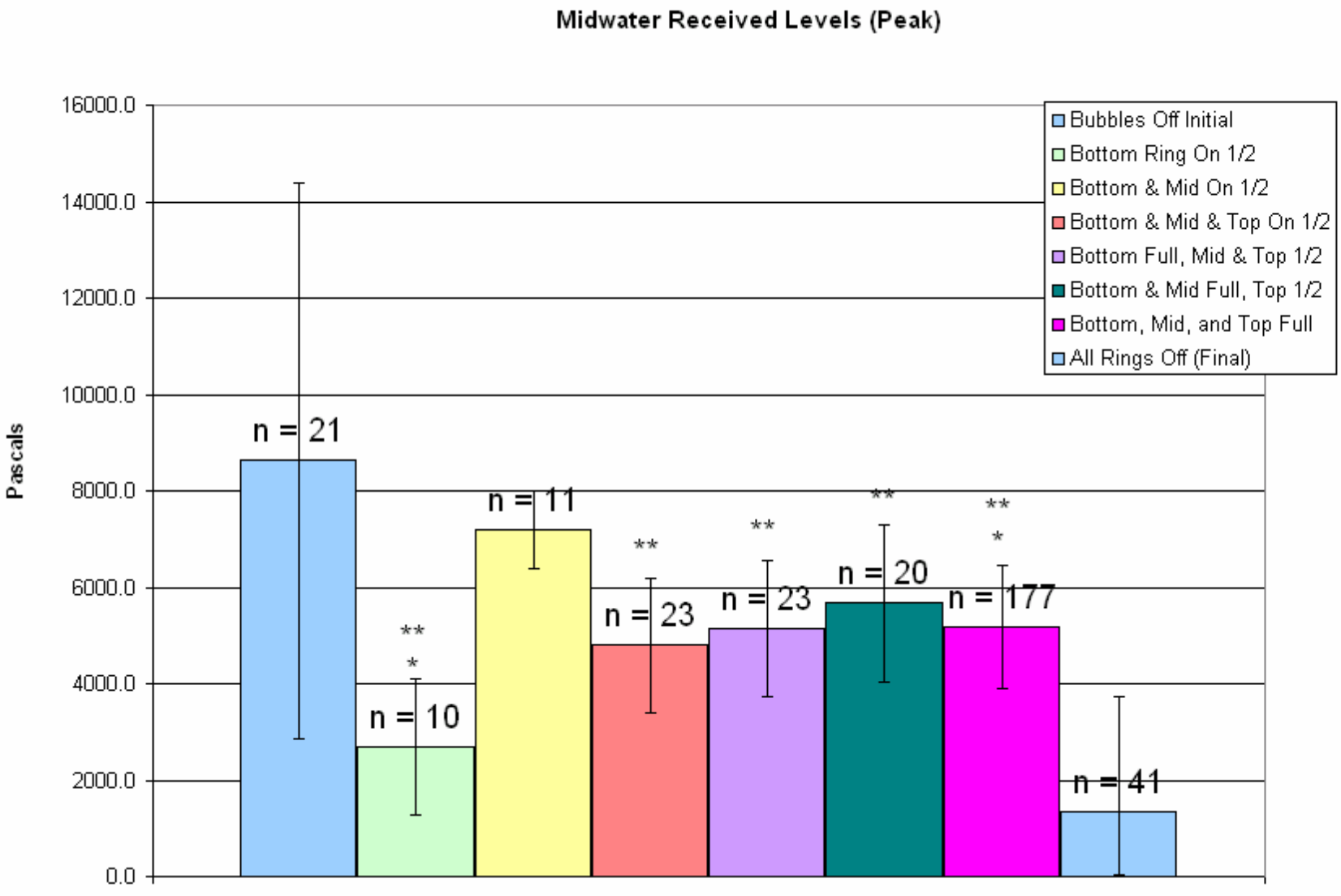

JUN 14 2005

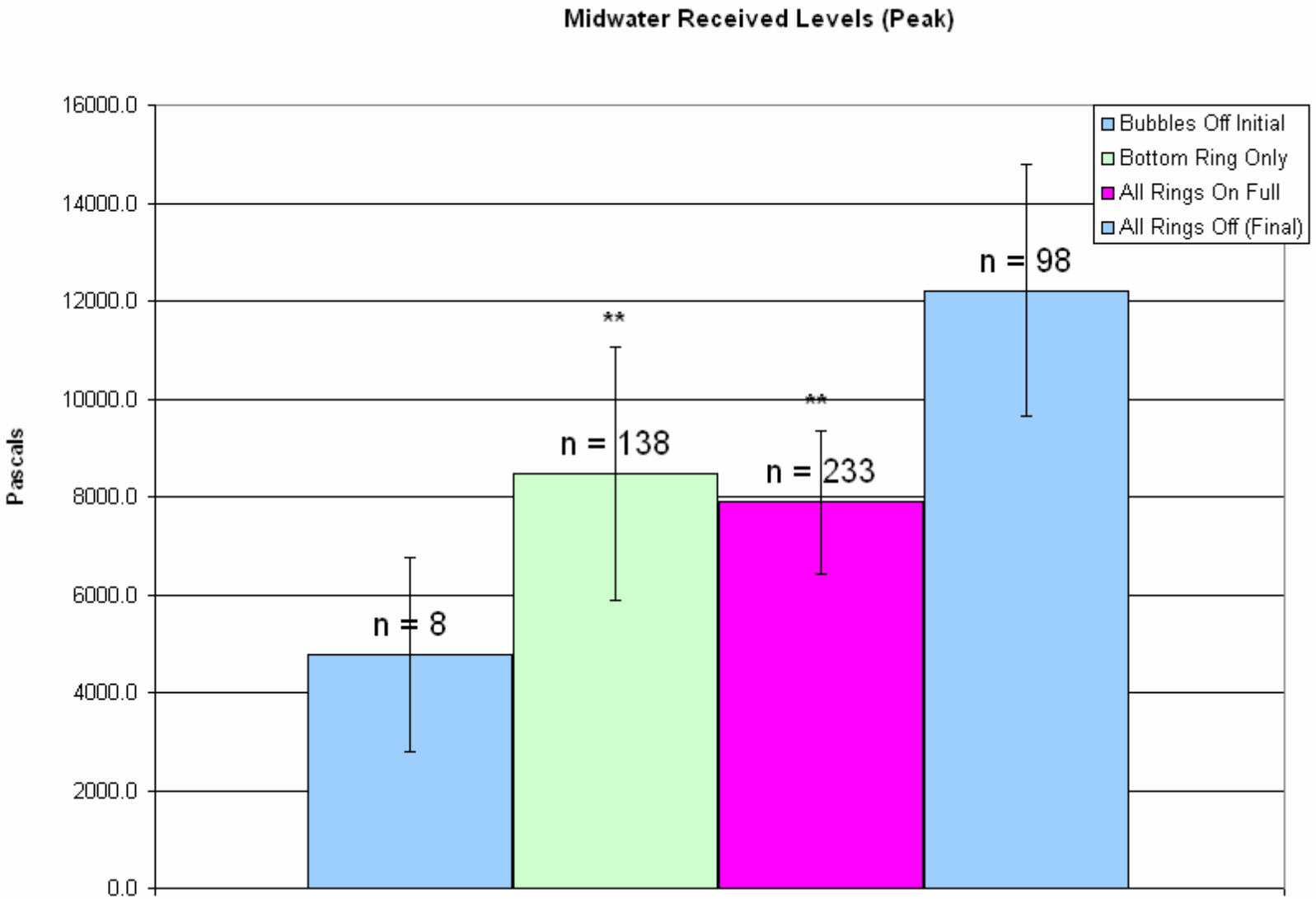
MITIGATION

- Bubble Curtain
- Sleeves
- Dry Coffer Dams
- Timing
- Driving above the MHHW line

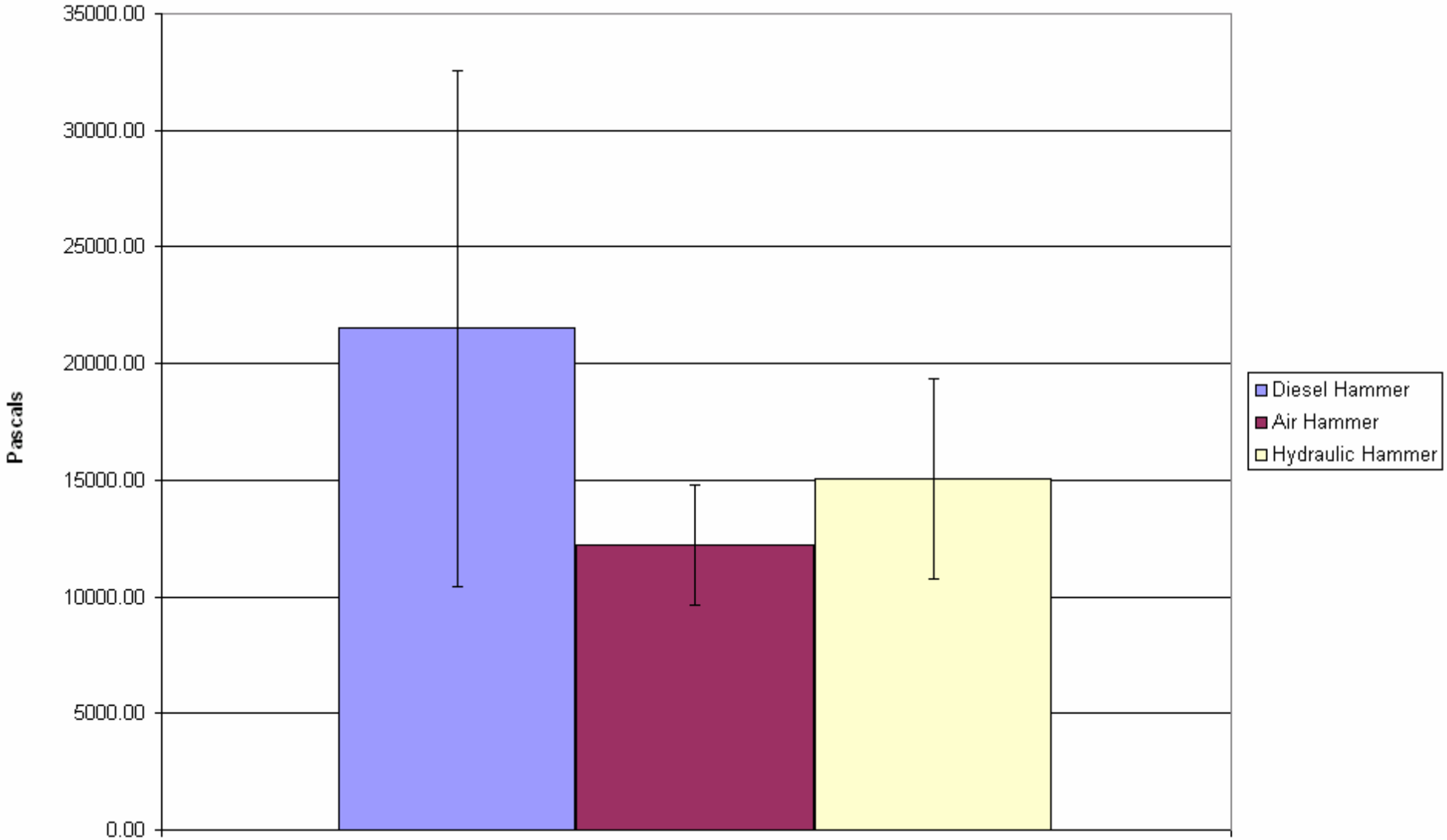
Friday Harbor


Dolphin
#3
Bridge Seat
FRONT STREET
EAST STREET
COMPLETE
NEW WALKWAY
RECONSTRUCT
TIE-UP TRESTLE
Tower
Phase 3
Jan to Feb 2005


Midwater Received Levels (Peak)
Pascals
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
Bubbles Off Initial
Bottom Ring On 1/2
Bottom & Mid On 1/2
Bottom & Mid & Top On 1/2
Bottom Full, Mid & Top 1/2
Bottom & Mid Full, Top 1/2
Bottom, Mid, and Top Full
All Rings Off (Final)
n = 21
n = 10
n = 11
n = 23
n = 23
n = 20
n = 177
n = 41
**
*
**
**
**
**
*


Midwater Received Levels (Peak)
Pascals
16000.0
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
Bubbles Off Initial
Bottom Ring Only
All Rings On Full
All Rings Off (Final)
n = 8
n = 138
n = 233
n = 98
**
**

Hammer Comparisons (bubbles off)



SEL Values for Each Pile

Preliminary Conclusions

- Preferred hammer type: Diesel
- Bubble curtain with one ring at bottom
- Need more analysis

CURRENT WSDOT ACTIVITIES

2005 PROJECTS

- SR 24 Bridge Replacement (Yakima River)
- Eagle Harbor Ferry Maintenance Facility
- Anacortes Ferry Terminal
- Winslow Ferry Terminal
- Hood Canal Bridge

2006 PROJECTS

- SR 202
- Mukilteo Test Piles (Concrete)

WHAT'S NEXT

- Gather more information on WSDOT pile driving efforts.
- Work with services to determine appropriate criteria (performance based not prescriptive)
- **Research**
  - NCHRP funding ($450K)
  - WSDOT Particle Velocity sensor funding ($150K)
  - WSDOT Data Analysis Funding ($40K)
  - Pooled Funding ($500K)

Jim Laughlin

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